Appendix D

Detecting and Monitoring Chemical Agents

INTRODUCTION

Separation and detection technologies make use of the attributes of a chemical that distinguish it from other chemical compounds and make it detectable by sensors (NRC, 1991). Distinguishing attributes include chemical reactions that cause color changes; the mass-to-charge ratio of the molecule; absorption and scattering of electromagnetic energy, particularly in the infrared to microwave region; reactions that cause unique emissions, such as chemiluminescence; physical separation; electrochemical interactions; and reactions with enzymes. A sensor is a device that produces a measurable response to a change in a physical condition, such as temperature or thermal conductivity, or to a change in chemical concentration (Cattrall, 1997; Janata, 1989; Taylor and Shultz, 1996).

Many detection technologies are based on spectrometry, the spectrum of mass or energy in the sampling device (Barker, 1999; Scimedia, 1999). Spectroscopy is the use of the absorption, emission, or scattering of electromagnetic radiation by atoms or molecules (or atomic or molecular ions) to qualitatively or quantitatively detect atoms or molecules (Scimedia, 1999). Mass spectrometers use the difference in mass-to-charge ratio of ionized atoms or molecules to separate them from each other. A sample is introduced into the instrument, a charge is imparted to the molecules in the sample, and the resultant ions are separated by the mass analyzer component. Mass spectrometry is useful both for determining chemical and structural information about molecules and for quantifying the concentration of atoms or molecules in a sample. The technique requires only a few nanomoles of analyte to determine characteristic information on structure and molecular weight. Tables D-1 and D-2 provide a summary review of the chemical detection and monitoring technologies and devices discussed below.

EXISTING TECHNOLOGIES

In the sections below, common technologies for detecting vapor-phase and aerosol-phase chemical agents as well as chemicals in other media, such as water, soil, and food, are described. Vapor-phase chemicals are volatile chemicals found as gases in air. Aerosol-phase chemicals are either dispersed in air as particles or are bound to fine particles.

Color-Change Chemistry

Color-change technology is based on chemical reactions that occur when some chemical agents interact with various solutions and substrates. The most common indicator of a reaction is a color change. Color-change detectors can detect nerve, blister, and blood agents with detection tubes, papers, or tickets to whose surface a substrate or reagent solution is applied (IOM, 1999). Many detection kits are complex and include multiple tests for specific agents or families of agents. Color-change methods are primarily qualitative in that they only detect the presence of an agent above a certain concentration threshold, but they are not reliable for determining chemical agent concentrations (U.S. Army SBCCOM, 1998).

Ion Mobility Spectrometry

Ion mobility spectrometry (IMS) operates by drawing air at atmospheric pressure into a reaction region where the constituents of the sample are ionized. Air and chemical agents in vapor-phase compounds form ion clusters when they are exposed to their parent ions. The mobility of the ion clusters is mainly a function of shape and weight. The agent ions travel through a charged tube where they collide with a detector plate, and a charge (current) is registered. A plot of the current generated over time provides a characteristic ion mobility spectrum. The intensity (height) of the peaks in the spectrum, which corresponds to the amount of charge, indicates the relative concentration of the agent. IMS technology has been used in mobile detectors to detect nerve, blister, and blood agents (IOM, 1999).

TABLE D-1 Estimates of Chemical Agent Exposure Limits

Chemical Agents	Lethal Exposure Limit Estimates	Other Established Exposure Limit Estimates
Nerve Agents		
GA	13	0.0001
GB	3	0.0001
GD	2	0.00003
GF	N/A	N/A
VX	3	0.00001
Choking Agents		
CG	100	0.002
DP	100	0.002
Blood Agents		
AC	150	0.003[a]
CK	400	0.008[a]
SA	200	0.004[a]
Blister Agents[b]		
HD, L, HNs[a]	~50	0.003
HL	50	0.003
PD, ED, MD, CX	~100	0.003[a]

[a] Limited operational temperature and humidity range.
[b] Representative exposure limits but not the specific volume for any single compound.

Infrared Absorption Spectroscopy

Infrared spectroscopy is the measurement of the absorption of mid-infrared light (2.5–50 µm wavelength) which can excite molecular vibrations to higher energy levels. The wavelength of infrared absorption bands work best for identifying organic and organometallic molecules (Dean, 1995; Scimedia, 1999).

Compounds in the air that absorb infrared energy can be quantified using open-path Fourier transform infrared (FTIR) spectroscopy. An FTIR spectrometer consists of a beam splitter that divides the incoming radiation into two beams. One beam is reflected by a fixed mirror; the other is sent to a moving mirror causing a variable optical path difference. Both beams are then reflected back to the beam splitter where they recombine and interfere according to their wavelength and optical path difference. A detector measures the intensity of the interfering beam as a function of the optical path difference. The result of this process is an interferogram. The optical path difference is measured with a monochromatic laser, and

TABLE D-2 Sensitivity of Chemical Agent Detection and Monitoring Equipment

	Detection Sensitivity to Chemical Agents (mg/m^3)				
Detection Equipment`	Nerve Agents (in µ drops)	Choking Agents	Blood Agents	Blister Agents (in µ drops)	Other Agents[a]
M8 and M9 Detection Paper (liquids only)	G agents 100 VX 100			H 100 µ drops	
M8A1 Alarm (ACAA)	GA 0.1–0.2 GB 0.1–0.2 GD 0.1–0.2 VX 0.2				
M22 (ACADA)	GA 0.1 GB 0.1 GD 0.1 VX 0.05			HD 2 L 2	
M90 D1A (AMAD)	G agents 0.02 VX 0.02		Sensitivity not available	H 0.2 L 0.8	
ICAD Miniature Detector	G agents 0.2–0.5	CG 25 CK 50	AC 50	HD 10 L 10	
M21 Alarm	G agents 90				
CAM Chemical Agent Monitor	G agents 0.03 VX 0.03			HD 0.1 HN agents 0.1	
ICAM-APD	G agents 0.1			H 2 L 2	
SAW Mini-CAD Alarm	GB 1 GD 0.12			HD 0.6	
Mini-CAMS	G agents 0.0001 VX 0.0001			H 0.003 L 0.003	
Gas Chromotography Systems	G and V < 0.0001	Many possible	Many possible	HD < 0.003 Others	

[a] For example, riot-control toxins.

the interferogram is converted to a spectrum by a Fourier transformation. Although FTIR has the capability of identifying chemicals in air with parts per billion (ppb) sensitivity, each chemical requires a different reference spectrum. In addition, when used with a mix of chemicals, FTIR requires spectral pattern-recognition software to separate the concentrations of individual species out of complex multicomponent spectra.

Another technology that makes use of infrared absorption spectroscopy is tunable infrared laser absorption spectroscopy. For many types of compounds, this technology is an attractive competitive alternative to FTIR because of its higher sensitivity and selectivity.

Differential Optical Absorption Spectrometry

Infrared light absorption has proven to be quite useful for measuring concentrations of atmospheric chemicals. However, it cannot be used to measure all chemicals of interest with the necessary level of specificity and sensitivity. Thus, absorption in the ultraviolet and visible regions of the spectrum is increasingly being used to detect chemicals in air. One example is differential optical absorption spectrometry, which measures the difference between the absorption at a wavelength where the species of interest has a distinct absorption peak and at another wavelength on either side of the peak (Vandaele and Carleer, 1999).

Aerosol Mass Spectrometry

The goal of aerosol mass spectrometry is to provide on-line, real-time chemical analysis of individual aerosol particles (Johnston, 1999). The chemical analysis characterizes aerosol particles in terms of bulk composition, surface composition, organic chemical species, and inorganic chemical species. An on-line system minimizes sampling artifacts caused by condensation, evaporation, or chemical transformation. A real-time system provides high temporal resolution and allows the system to monitor rapid changes in composition. Current devices include the following instrumentation:

- an aerosol inlet that pulls sampled particles from atmospheric pressure into a vacuum and transfers them to a laser beam for analysis
- an instrument for particle detection and sizing that can synchronize the arrival of a particle with a desorption laser pulse and determine the particle size
- a mass spectrometer that can desorb and ionize constituents in the particle and obtain a complete mass spectrum from the burst of

ions produced (older instruments use lasers to vaporize the particle constituents; newer instruments use hot surfaces)

Raman Spectroscopy

When electromagnetic radiation is passed through a transparent medium, some of the radiation is scattered in different directions by chemical species present in that medium (Scimedia, 1999). The wavelength of a very small fraction of the scattered radiation differs from the wavelength of the incident beam; this is the Raman-scattered light. The wavelengths of the scattered light are shifted from those of the incident light by the energies of molecular vibrations. The mechanism of Raman scattering differs from infrared absorption so that Raman and infrared spectra provide complementary information. Raman spectroscopy is used for determining structure, multicomponent qualitative analysis, and quantitative analysis. IR can be used to detect chemical agents in air samples.

Nondispersive Infrared Spectroscopy

The infrared region of the electromagnetic spectrum between 2.5 and 25 micrometers has proven to be a valuable range for the identification and quantification of gaseous molecular species. When infrared radiation passes through a gas, radiation is absorbed at specific wavelengths defined by infrared filters. These wavelengths are characteristic of the vibrational structure of the specific gas molecules. Nondispersive infrared spectroscopy technology is used in mobile detectors to detect blister and nerve agent vapors.

Phosphorus Chemiluminescence

Chemiluminescence is a technique that uses quantitative measurements of the optical emission from excited chemical species to determine analyte concentrations. The excitation energy for analytes in chemiluminescence is produced by a chemical reaction of the analyte and a reagent. Chemiluminescence can take place in either the liquid or gas phase. Phosphorus chemiluminescence detectors (PCDs) can be used to detect many chemical agents (Stedman, 1999) and are used for gas chromatography. PCDs can detect electromagnetic radiation in a system with very low background. Because the energy necessary to excite the analytes does not come from an external light source like a laser or lamp, there is no problem from excitation source scattering. The major limitation of PCDs involves the dark current of the photomultiplier necessary to detect the analyte light emissions.

Light Detection and Ranging

A light detection and ranging (lidar) system uses laser pulses to measure atmospheric constituents, such as aerosol particles, ice crystals and water vapor, or trace gases, such as chemical agents (U.S. Army SBCCOM, 1998). Every gaseous chemical species absorbs light in a unique way. One gas absorbs light at certain wavelengths; others absorb it at different, well defined wavelengths. A lidar device transmits short pulses of laser light into the atmosphere. As the laser beam travels, its intensity decreases due to scattering by natural airborne aerosols and particles. Some of the light is backscattered to a detector adjacent to the emitting laser, which measures the amount of light that is backscattered. Because the light takes longer to return from the more distant ranges, the time delay of the return pulses can be converted to the corresponding distance between the point of scattering in the atmosphere and the lidar detectors. The result is a profile of atmospheric scattering versus distance. Vapor molecules in the air will absorb scattered light if the laser wavelength matches the molecule's absorption profile. An analysis of the absorption signal can yield information about the distribution of chemicals in the atmosphere.

Differential absorption lidar (DIAL) uses light of two different wavelengths, only one of which is absorbed by the gas under investigation, so that a differential measurement can be performed. The nonabsorbed wavelength is used as a reference to eliminate atmospheric propagation effects. Lidar provides a method for remote (or stand-off) detection of chemicals in the atmosphere.

Gas Chromatography

Gas chromatography is used to detect a variety of chemical compounds. Chromatography is a separation method that relies on differences in partitioning behavior between a flowing mobile phase and a stationary phase to separate the components of a mixture. A column (or other support) holds the stationary phase, and the mobile phase carries the sample through it. Sample components that partition strongly into the stationary phase spend a longer time in the column and are separated from components that stay predominantly in the mobile phase and pass through the column faster. As the components emerge from the column, they can be quantified by a detector or collected for further analysis. In gas chromatography, the mobile phase is a gas, and the stationary phase is usually a liquid on a solid support or sometimes a solid adsorbent. Like mass spectrometry, gas chromatography methods also offer high sensitivity and specificity in detecting chemical agents in many sample forms.

A gas chromatograph can be combined with a detection method for on-line analysis. Examples of such “hyphenated techniques” include gas chromatography/mass spectroscopy, gas chromatography/FTIR, and diode-array ultraviolet/visable absorption spectroscopy.

Surface Acoustic Wave Technology

Surface acoustic wave (SAW) technology is based on the attenuation of solid-state acoustic surface waves through chemical interactions between the analyte and a chemically selective coating on the surface. SAW sensors detect changes in the properties of acoustic waves as they travel at ultrasonic frequencies at the surface interface between the coating and a piezoelectric material, such as quartz, lithium tantalate, lithium niobate, or langasite crystals. These materials convert radio frequency electrical signals into Rayleigh surface acoustic waves through a carefully designed transducer. The basic transduction mechanism involves interaction of these waves with surfaceabsorbed gases. A second transducer detects the acoustic wave as a delayed, attenuated replica of the input electrical signal. Multiple sensor arrays with multiple coatings, each having a different molecular selectivity based on chemical solubility, and pattern recognition algorithms are used to identify agent classes and reject interferent responses that could cause false alarms (IOM, 1999).

Although SAW transducers respond to agents with no coatings, special polymer coatings are used to enhance the response (signal-to-noise ratio) from the target agents and minimize false alarms from battlefield interferents. One coating provides various responses to several different chemical warfare agents, and the differences are usually large enough for the device to differentiate among agents.

Current technology can detect and identify a wide range of chemical warfare agents with only six different coatings. However, more coatings may be needed for higher degrees of specificity for large target populations like TICs. If the new agents respond to existing coatings, it will be fairly simple to change the detection software to recognize them. If not, new coatings must be developed. SAW sensors are used in mobile detectors to detect nerve and blister agents. With further development, SAW technology could also potentially detect a large number of chemical compounds and biological agents.

Electrochemical Sensor Technology

An electrochemical sensor detects and measures changes caused by the interaction between the chemical agent and the properties of an electrical circuit (Taylor and Schultz, 1996). Fundamentally, electrochemistry is based on a chemical reaction that occurs when the chemical agent enters the detection region and produces some change in the electrical potential. This change is normally monitored through an electrode. A threshold concentration of agent is required, which corresponds to a change in the monitored electrical potential. Electrochemical sensor technology can be used in a wide variety of configurations. Currently, it is used in mobile detectors to detect blister, nerve, blood, and choking agents.

Photo-ionization Technology

Photo-ionization detectors (PIDs) operate by passing an air sample between two charged metal electrodes in a vacuum region irradiated with ultraviolet radiation, thus producing ions and electrons. The negatively charged electrode collects the positive ions, thus generating a current that is measured by an electrometertype electronic circuit. The measured current can then be related to the concentration of the molecular species present. PIDs are used in mobile detectors to detect nerve, blister, and mustard agents.

Flame Photometry

In flame photometry, an air sample is burned in a hydrogen-rich flame. The compounds present emit light of specific wavelengths in the flame. An optical filter is used to let a specific wavelength of light pass through, and a photosensitive detector produces a representative response signal. Because most elements emit a unique, characteristic wavelength of light when burned in this flame, the flame photometer can detect specific elements. Flame photometers are commonly used with gas chromatographs. Sulfur and phosphorous flame photometry are often used to detect mustard and nerve gas, respectively.

Photoacoustic Infrared Spectroscopy

Like infrared spectroscopy, photoacoustic infrared spectroscopy (PIRS) uses the selective absorption of infrared radiation by chemical agent gases to identify and quantify the agent present. Pulses of a specific wavelength of infrared light are sent into a sample through an optical filter, and the light transmitted by the filter is selectively absorbed by the gas being monitored, which increases the temperature and pressure of the gas. Because the light entering the cell is pulsating, the pressure in the cell fluctuates, creating an acoustic wave directly proportional to the concentration of the gas in the cell. Microphones mounted inside the cell monitor the acoustic signal and send results to the control station. PIRS technology is fairly well established, but its use for chemical warfare agent detection is fairly new. It is anticipated that a large number of agents can be detected with this technology.

Millimeter and Submillimeter Wave Detection

The molecules of many compounds absorb waves in the infrared region of the electromagnetic spectrum, and the wavelength at which absorption occurs is unique to specific compounds, which provides identifiers for different compounds. Rotational and vibrational interactions occur with electromagnetic radiations that have longer (submillimeter to millimeter) wavelengths. These regions include the far-infrared and radio frequency microwave spectrum. Research on the absorption of these wavelengths for detecting chemical agents is under way (U.S. Army SBCCOM, 1998). If the absorption of energy at these wavelengths is sufficient, microwave spectroscopy-based technologies similar to infrared spectroscopy methods may be another way of detecting chemical agents.

EMERGING TECHNOLOGIES

Aerosol Mass Spectrometry

Only a few on-line techniques have been developed for detecting and characterizing small aerosol particles. Conventional methods involve isolating particles on filters and subsequent analysis performed in the laboratory. The isolation processes often disturb the aerosol and thus render the data questionable because the particles often evaporate or react before analysis.

Newer spectrometers using gentler vaporization strategies will probably overcome this problem. An example of an emerging technology based on aerosol spectrometry is aerosol time-of-flight mass spectrometry (ATOFMS) (Noble and Prather, 1996). This technique provides the size and chemical composition of individual aerosol particles in real time. Some examples of aerosol systems that are being characterized in the laboratory using ATOFMS include secondhand tobacco smoke, suspended soil dust, sea salt aerosols, and a variety of combustion particles. In recent field studies, transportable ATOFMS instruments were strategically positioned at sites where the evolution of single particles in the atmosphere could be monitored over time. In regional and international studies, these transportable instruments are being used to study the direct effects of aerosols on visibility, pollution levels, and global radiation.

The ATOFMS uses lasers to vaporize the particle constituents. Some newer instruments use hot surfaces rather than lasers for aerosol vaporization. Hot surface vaporization tends to preserve organic molecular structure better and prevent its fragmentation in the laser vaporization/ionization instruments. If these "hot-surface" systems can preserve molecular structure, they may be crucial to the future identification of specific chemical agents and TICs bound to aerosols.

Enzyme Methods

Enzymes can be used with immunoassays to detect the presence of, and quantify the concentration of, many chemical substances (Ngo and Lenhoff, 1985). The essential components of an enzyme immunoassay are an antibody that binds to a specific target substance (chemical agent) and an enzyme that makes detection of the bound antibody possible. Immunoassays performed in a solution, for example, respond to the initial reaction of the antibody and its chemical, which then modulates the catalytic activity of the enzyme, allowing detection. The sensitivity of an enzyme immunoassay depends on how well antibodies home in on a particular antigenic target, such as a chemical agent or a protein, a bacterial or viral antigen, or other antibodies. A detection system that combines this specificity with the catalytic ability of some enzymes to convert colorless chemicals to brightly colored products could be adapted to a wide range of applications. The best known enzyme immunoassay technique is enzyme-linked immunosorbent assay (ELISA). Immunoassays are increasingly being used to detect environmental contaminants. Enzyme immunoassays can be very sensitive (down to the parts per trillion [ppt] level) and very specific. However, they are much too slow for rapid chemical detection. Another problem is that some substances do not readily create antibodies.

CURRENT DETECTION AND MONITORING EQUIPMENT

Currently available equipment for detecting and monitoring chemical agents range from simple systems, such as detection paper, to complex mobile sampling vehicles, such as the FOX vehicle. The following subsections contain a review of the capabilities and limitations of these systems, most of which have been developed singly or jointly by branches of the military (a few have been commercially developed but are available for military use). The information for this review was provided by a number of sources, including other National Research Council reports (IOM, 1999; NRC, 1997a, 1997b); documents provided by the U.S. Department of Defense (DoD) (DoD 1997, 1998, 1999; U.S. Army, 1992, 1994; U.S. Army and U.S. Marine Corps, 1996); briefings to the principal investigator and advisory panel by the U.S. Army Soldier and Biological Chemical Command (U.S. Army SBCCOM, 1998); Jane's Guidebook (Ali et al., 1997);

and internet resources (Jane's Information Group, 1999; JSMG, 1999; U.S. Army SBCCOM, 1999; U.S. Navy, 1999).

Detection Papers

The M8 and M9 detection papers provide rapid (less than one minute), inexpensive tests for the presence of liquid mustard or nerve agents. The paper is used only for screening, and results must be verified by more accurate detection methods, particularly because of the paper's propensity to show false positive results for some substances, such as petroleum products and antifreeze.

M8 Chemical Agent Detector Paper

M8 paper is used by ground troops to detect liquid chemical agents. It is capable of detecting Levinstein mustard (H) and Lewisite blister agents and fluorine- or cyanide-containing organophosphates (G) and sulphur-containing organophosphorous compounds (V) nerve agents. It is not used as the sole basis for agent identification, however. M8 paper is supplied in the M256A1 Kit and the M18A2 Chemical Agent Detection Kit.

M9 Chemical Agent Detector Paper

M9 paper, which is similar to M8 paper, comes in a long dispenser roll. M9 paper is an adhesive-backed, tapelike material designed to be worn on the outside of clothing or placed on vehicles, equipment, or supplies that may be exposed to chemical agent droplets.

Detection Kits

Detection kits include test papers, detector tickets, and/or sample detection tubes. Current detection kits are the M256 kits and the M18 kit.

M256A1 and M256A2 Chemical Agent Detector Kits

The M256A1 contains disposable plastic sampler detectors, a booklet of M8 paper, and a set of instruction cards. The sampler detectors are enzyme-based detector "tickets" that change color to indicate low concentrations of cyanide, vesicant, and nerve agents in vapor form. The tests take approximately 15 minutes and may provide a negative reading at concentrations that are below the immediately-dangerous-to-life-and-health (IDLH) level but are still hundreds of times higher than the AEL.

The M256A2 kit contains a colorimetric device for measuring the concentration of selected airborne chemicals and has approximately the same sensitivity.

M18A2 Chemical Agent Detection Kit

The M18A2 comes with disposable tubes for detecting cyanide, phosgene, Lewisite, sulfur mustard, and nerve agents GA (tabun), GB (sarin), GD (soman), and VX. Tests for each take two to three minutes but must be conducted in series, not simultaneously.

Point (Local) Chemical Detector/Alarm Systems

Local detection systems produce an alarm or warning and work at close range (point detection). Most of these are "alarm-only" systems that do not provide any information about agent concentrations except that they are above the sensitivity level of the detector. Many do not even identify the agent that set off the alarm.

M8A1 Automatic Chemical Agent Alarm

The M8A1 is an automatic chemical agent detection and warning system designed for the point detection of nerve agent vapors or inhalable aerosols by ionization methods in a baffled-flow electrode configuration that filters out the lighter background ions from the heavier agent ions. This system has a response time of less than two minutes and can detect GA, GB, and GD with a sensitivity of 0.1 to 0.2 mg/m and VX with a sensitivity of 0.4 mg/m. The M8A1 alarm system, which uses IMS technology, is being replaced by the M22 automatic chemical agent detector alarm (ACADA), which also uses IMS technology. DoD decided to replace IMS with SAW technology in the joint chemical agent detector (JCAD) system, which will replace the M8 and M22 point detectors and the chemical agent monitor/improved chemical agent monitor (CAM/ICAM) monitors, which are also based on IMS technology.

M22 Automatic Chemical Agent Detection Alarm

The M22 is an "off-the-shelf," automatic, chemical agent alarm system based on IMS technology that is capable of detecting and identifying standard blister and nerve agents. The M22 system is man-portable, can operate automatically after system start-up, and provides an audio and visual alarm. An important feature of the M22 is that it can be linked to other systems, such as the multipurpose integrated chemical agent detector (MICAD), to support battlefield automation systems.

M90 Automatic Agent Detector

The M90 automatic agent detector (AMAD) is a portable unit used to indicate the presence of nerve, blister, and blood agents. The M90, which uses IMS techniques, is an alarm-only device that can monitor up to 30 chemicals in parallel. The M90 is a fast-acting, relatively sensitive device that provides an alarm in about 10 seconds for nerve agents and mustard and about 80 seconds for lewisite.

Individual Chemical Agent Detector

The ICAD is an 8-ounce pocket-mounted device that simultaneously detects nerve, choking, blood, and blister agents based on electrochemical techniques. It is easy to operate, requires only minutes of training time, and has both visual and audible alarms. Sensitivities are in the range of 0.2 to 0.5 mg/m for G agents, 5 mg/m for VX, and 10 to 50 mg/m for blood, blister, and choking agents. ICAD was developed for the U.S. Marines.

Shipboard Chemical Agent Point Detection System

The CAPDS is a fixed system capable of detecting nerve agents in vapor form using a baffled-flow electrode configuration ionization technique. It generates an alarm signal that is sent to the Damage Control Central and the bridge. This system is installed on most surface combatant ships.

Stand-off Chemical Alarm Systems

Stand-off systems produce an alarm or warning from a distance, warning of an agent before troops move into the area. One stand-off system, the M21 remote sensing chemical agent alarm known as RSCAAL, detects chemical agent vapor clouds. RSCAAL was type classified standard and approved for full-rate production in March 1995. The M21 alarm detects nerve and blister agent clouds at line-of-sight distances out to 5 km. It is being issued to nuclear, biological, and chemical (NBC) reconnaissance teams for use either on a tripod or in conjunction with the NBC FOX reconnaissance vehicle. The M21 alarm, which uses passive FTIR detection technology, must be stationary to work effectively. An airborne version, called the joint service lightweight standoff chemical agent detector (JSLSCAD), is under development.

Point (Local) Monitoring Devices

Point (local) monitoring devices are designed to collect samples and monitor chemical concentrations in the environment in which troops are currently located.

Chemical Agent Monitor (CAM) and Improved Chemical Agent Monitor (ICAM)

Both the CAM and ICAM use IMS technology. These portable, handheld, point-detection instruments monitor nerve or vesicant agent vapors. They provide graduated readouts (eight bars). They detect vapors of chemical agents by sensing molecular ions of specific mobilities (time of flight) and use timing and microprocessor techniques to reject interference. The monitors, which consist of a drift tube, signal processor, molecular sieve, membrane, and expendables (e.g., batteries, confidence tester, dust filters, buzzer, and battery pack), can detect and discriminate between vapors of nerve and mustard agents. The monitors are 4-inches by 7-inches by 15-inches and weigh approximately 5 pounds. The ICAM has minimal maintenance requirements.

Response time depends on concentration but generally takes from 10 to 60 seconds. Minimum levels detectable are about 100 times the AEL for the nerve agents and about 50 times the AEL for vesicants. One obvious drawback, therefore, is an inability to check the efficacy of decontamination, both in the field and subsequently at treatment facilities.

ICAM-Advanced Point Detector (APD)

The ICAM-APD is based on IMS technology and integrates ICAM and commercial-off-the-shelf components. ICAM-APD can simultaneously detect both nerve and blister vapor and aerosol agents.

SAW Mini-Chemical Agent Detector

The SAW Mini-CAD is a commercially available, pocket-sized instrument that can automatically monitor for trace levels of toxic vapors of both sulfur mustard and the G nerve agents with a high degree of specificity. The instrument is equipped with a vapor-sampling pump and a thermal concentrator to provide enriched vapor sample concentration to a pair of high-sensitivity coated SAW microsensors. All subsystems are designed to consume minimal amounts of power from onboard batteries. Optimal use of the SAW Mini-CAD requires a compromise among the conflicting demands of response time, sensitivity, and power consumption.

Maximum protection requires high sensitivity and a rapid response. The SAW Mini-CAD has more sensitivity with increased sampling time; a faster response can be provided at a lower sensitivity setting. Testing of the SAW Mini-CAD has been performed with chemical warfare agents GD, GA, and HD at a variety of concentrations and humidity levels, and the response rate was not significantly affected by these changes (IOM, 1999). The SAW Mini-CAD can also record some data.

Gas Chromatography Systems

The state-of-the-art systems for detecting any chemical agent are laboratory-quality gas-chromatography systems, most of which are heavy (up to 100 pounds). They also require a 120 or 220 V AC power supply and, thus, have limited portability. Although gas chromatography systems take up to 10 minutes for an analysis, they are highly sensitive and very specific, and they can detect most chemical warfare and many toxic chemical agents below the AEL levels. Gas chromatography systems, which are versatile and can detect thousands of chemicals, come with extensive chemical spectra libraries. Examples of gas chromatography systems are the Viking Spectratrack GC/MS, which comes with a library of 62,000 chemicals, and the Hewlett-Packard 6890 Gas Chromatograph with flame photometric detector.

Continuous Air Monitoring Systems (Mini-CAMs)

The mini-CAM is a continuous air-monitoring system that uses gas chromatography and selected detectors and samplers to monitor for the presence of chemical agents. It weighs 10 pounds and is easily portable. Mini-CAMs were developed for monitoring air at storage and demilitarization facilities. They can detect most nerve, blood, blister, and choking agents at the Surgeon General's 8-hour time-weighted AEL. They have about a five-minute detection time and can operate 24 hours a day for up to seven days. Operation of a mini-CAM requires about eight hours of training. Mini-CAMS can be used either in a fixed laboratory or vehicle mount.

Automatic Continuous Air Monitoring System (ACAMS)

The ACAMS is used to monitor for chemical agents in plants. The ACAMS has an intrinsic response time of four to five minutes and "significantly shorter response times for most releases" (NRC, 1999, p. 30). Detection is accomplished through the use of a gas chromatograph equipped with a flame photometric detector and is interpreted by computer analysis. However, the ACAMS is subject to frequent false alarms because it cannot differentiate well between an agent and other commonly encountered organic contaminants (e.g., fuel, diesel exhaust, and antifreeze).

Stand-off Monitoring Systems

The AN/KAS-1/1A chemical warfare directional detector is a FLIR-based electro-optic sensor that remotely detects the presence of nerve agents. It provides stand-off chemical agent detection capability for surface ships and has been adapted for fixed-site shore facilities. The AN/KAS-1/1A provides images of the infrared portion of the electromagnetic spectrum. A series of optical filters are actuated by the operator to determine if suspicious objects in the field of view are, in fact, chemical agent clouds. The AN/KAS-1/1A also has a remote video hookup for monitoring and recording the field of view from a second location, typically the ship's Combat Information Center. AN/KAS-1A systems are currently mounted on surface ships.

Vehicle-Mounted Detection Systems

M93A1 FOX Nuclear, Biological, Chemical Reconnaissance System (NBCRS)

The NBCRS is a lightly armored, wheeled vehicle capable of detecting, identifying, marking, sampling, and reporting NBC contamination on the battlefield. A three-person NBCRS crew uses a sophisticated suite of nuclear and chemical alarms and detectors that have been integrated into the vehicle chassis. With the onboard RSCAAL, the crew can detect chemical agent clouds as far as 5 kilometers away.

Water Testing Systems

The only currently available system for testing water, the M272 water testing kit, was first fielded in 1984. It is designed to detect and identify hazardous levels of chemical agents in treated or untreated water. In seven minutes, the M272 can detect and identify agents by color-changing reactions. Its detection sensitivities are 0.02 mg/L for nerve agents, 2 mg/L for mustard and lewisite, and 20 mg/L for cyanide.

EMERGING DETECTION AND MONITORING EQUIPMENT

In addition to existing point-detection and monitoring capabilities, new equipment is being explored and developed to provide more sensitive and specific point and stand-off chemical detection. The following equipment is under development.

Joint Chemical Agent Detector (JCAD)

The JCAD will employ SAW technology to detect nerve, blood, and blister agents. The system is being designed to be lightweight and portable, to reduce the number of false alarms, and to detect new forms of nerve agents. JCAD will be a detector, or network of detectors, capable of automatically detecting, identifying, and quantifying chemical agents inside aircraft and shipboard interiors, providing hand-held monitoring capabilities, and protecting individual soldiers, sailors, airmen, and marines. JCAD is planned to be available in 2002 as a modular system that will replace all current point detectors and hand-held monitors. The detector unit for individual soldiers will weigh less than 2 pounds and will be less than 40 cubic inches in size. It will be carried in a pouch attached to the load-bearing equipment. The detector unit will have a snap-on preconcentrator accessory that increases detection sensitivity to levels that will warn soldiers to take protective action against low-level hazards before mission performance is degraded. The detector unit will also have an air sampler accessory that snaps onto the detector unit and generates pulses of warm air that can liberate chemical agent molecules trapped on surfaces. The JCAD detector unit with the preconcentrator accessory will be mounted inside aircraft, vehicles, and fixed-site facilities.

JCAD will use a powerful microprocessor to analyze, evaluate, and store chemical detection units. It will be equipped with serial communication ports that can be integrated with military communication systems and the global positioning system (GPS) to send detection data to the joint warning and reporting network (JWARN) and command and control systems. The serial ports will also provide the capability of uploading unit detection data on demand and downloading software updates to individual detector units. JCAD will be able to detect TICs. DoD plans to procure 250,000 JCAD units to replace and bolster the current inventory of about 65,000 M8 and M22 alarms.

Joint Services Lightweight Standoff Chemical Agent Detector (JSLSCAD)

The JSLSCAD is a passive, infrared detection unit based on FTIR spectrometry. The JSLSCAD signal processing hardware is being designed to discriminate between chemical targets and nontoxic species in a complex battlefield environment. The device is being designed to detect nerve and blister vapor clouds at a distance of up to 5 km. It will be smaller than the M21 and will not have to be stationary to work effectively.

Improved Point Detection System (IPDS)

The IPDS is an IMS-based, point chemical-detection system with an algorithm library and embedded data processing. This system automatically detects and warns of nerve and blister agent vapors at low concentrations and has the capability of rejecting common shipboard interference. IPDS will be deployed as part of the detection suite aboard ships and is intended to replace the current CAPDS.

Joint Services Lightweight NBC Reconnaissance System (JLNBCRS)

The JLNBCRS is being designed to provide point and stand-off intelligence for real-time field assessment of NBC hazards. The system will be a vehicle-mounted suite of equipment and software that can detect, collect, analyze, mark, and disseminate NBC data and can be transported by air. Two variants, the high-mobility multipurpose wheeled vehicle and the light armored vehicle, will house the same equipment and offer on-the-move stand-off capability. Timely automated, digital information, combined with meteorological and positioning information, will provide commanders with more options for merging NBC information with their tactical, operational, and strategic plans.

Shipboard Automatic Liquid Agent Detector (SALAD)

SALAD is an automatic, exterior, liquid agent point detection and monitoring system that will detect and set off an alarm in the presence of liquid nerve and blister agents. SALAD will consist of a detector unit that uses chemically treated paper, optical scanners, and a central processing control unit to automatically set off an alarm in Damage Control Central and on the bridge.

Joint Chemical/Biological Agent Water Monitor (JCBAWM)

The JCBAWM will be a portable device that can detect, identify, and quantify agents in water. It will allow the user to sample water and receive a digital readout of the composition. The technology for this monitor is still under review.

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